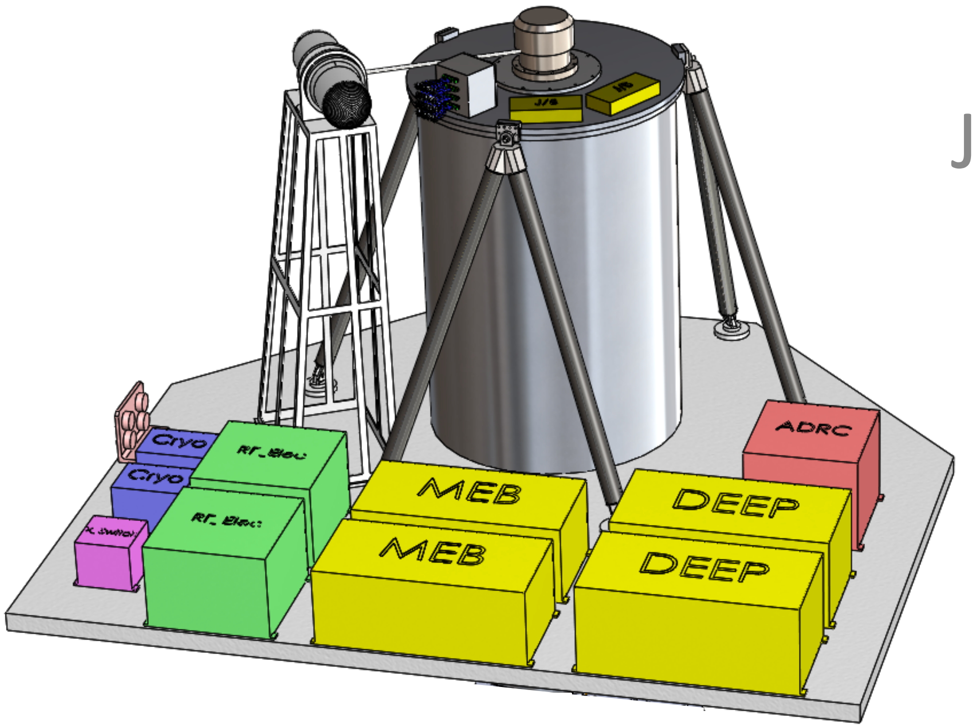
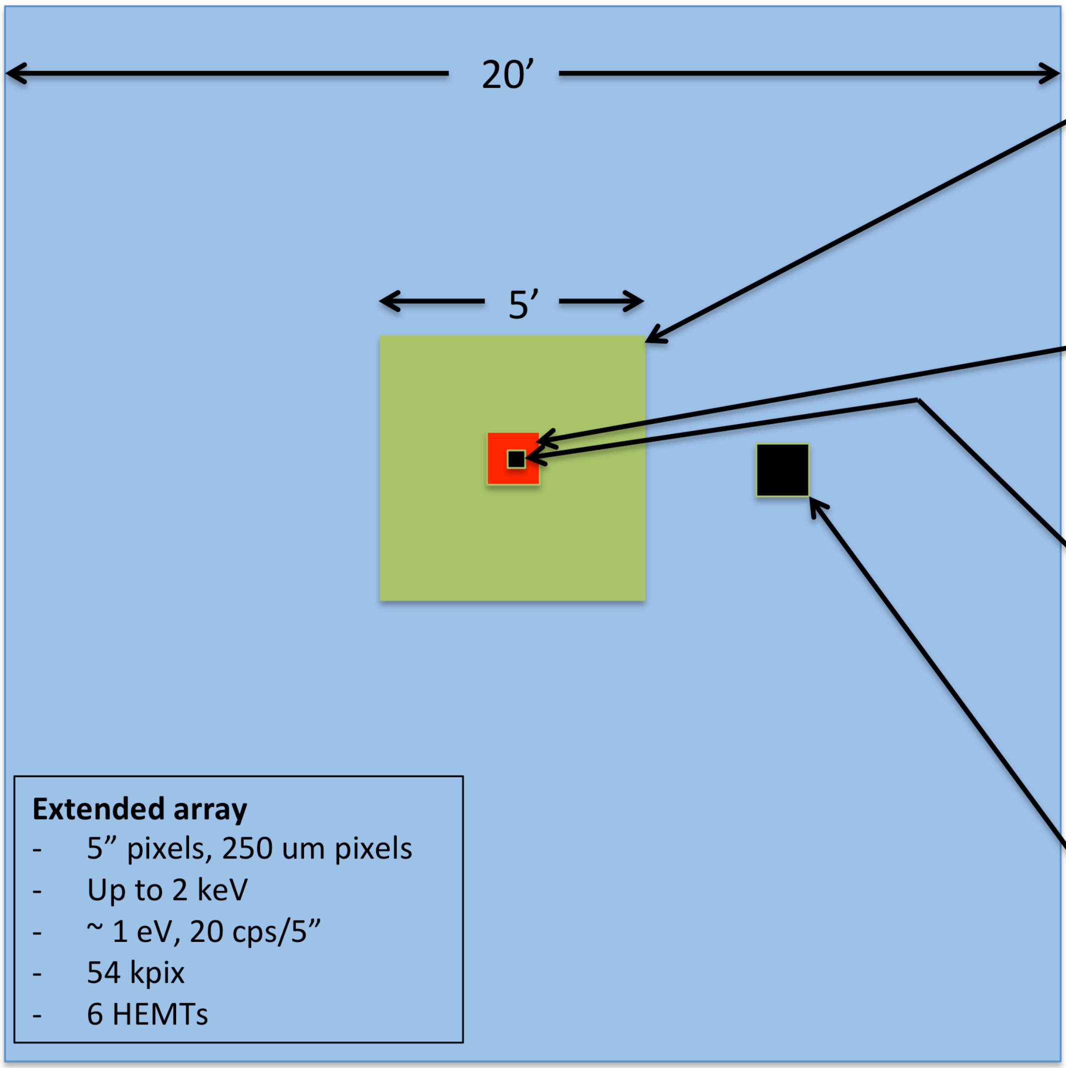
Lynx X-ray Microcalorimeter Specifications & Requirements



Simon Bandler

January 25, 2018

Lynx X-ray Microcalorimeter Array Layout



Main array
- 1” pixels, 5’ FOV, 50 um pixels
- ~ 3 eV, 10 cps/hydra (5”)
- up to 7 keV
- 86.4 kpix
- 10 HEMTs

Enhancement main array:
- 0.5” pixels, 1’ FOV, 25 um pixels
- ~ 1.5 eV, 10-20 cps/hydra-25 (2.5”)
- up to 7 keV
- 12.8 kpix
- 6 HEMTs

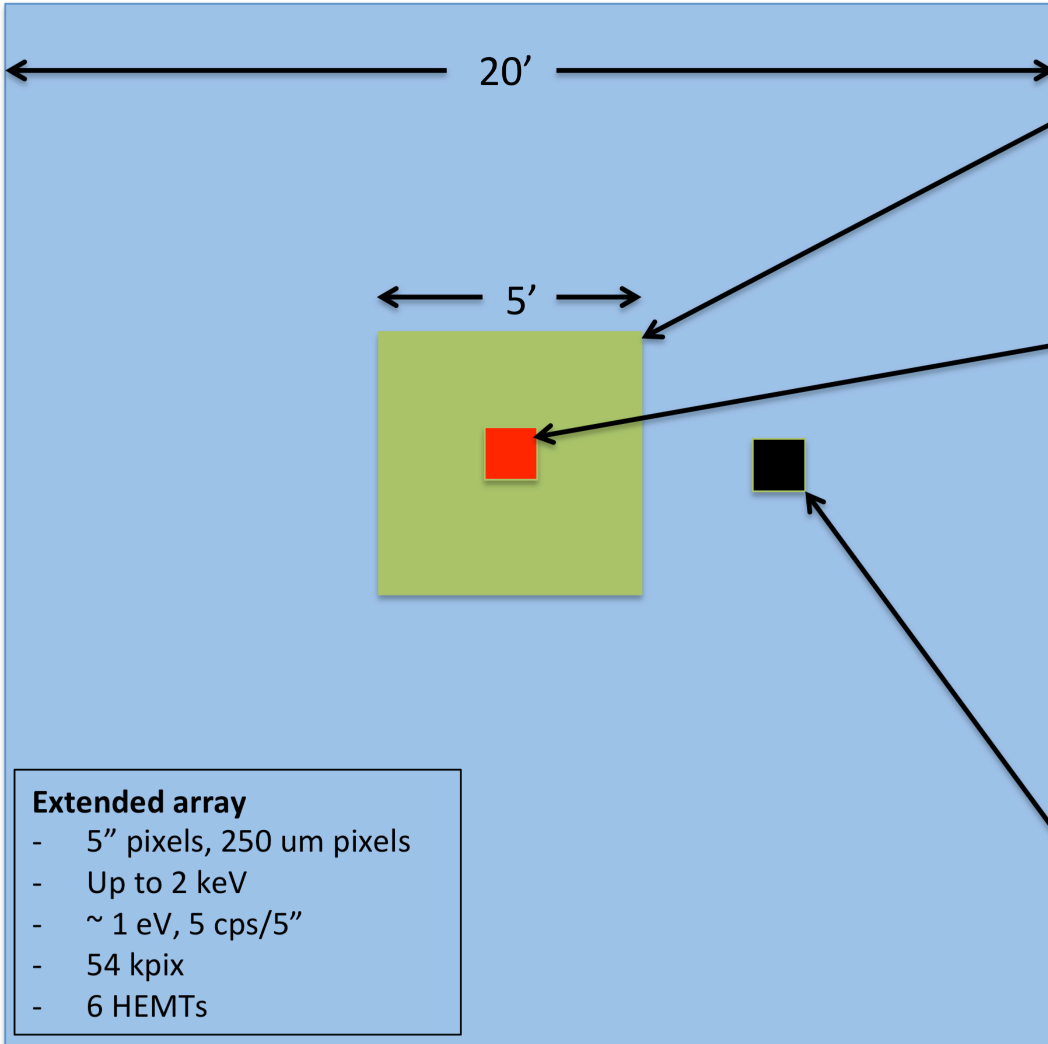
High-res inner array:
- 0.5” pixels, 20” FOV, 25 um pixel
- ~ 1.5 eV, 20 cps/hydra-4 (1”)
- up to 7 keV
- 1.6 kpix
- 4 HEMTs

Ultra-hi-res array
- 1” pixels, 1’ FOV, 50 um pixels
- 0.3-0.4 eV (up to ~ 0.75 keV)
- Count rate ~ 80 cps/1”
- 3.6 kpix
- 6 HEMTs

Extended array
- 5” pixels, 250 um pixels
- Up to 2 keV
- ~ 1 eV, 20 cps/5”
- 54 kpix
- 6 HEMTs

Lynx X-ray Microcalorimeter Array Layout

1 eV or 2 eV extended array



Extended array
- 5” pixels, 250 um pixels
- Up to 2 keV
- ~ 1 eV, 5 cps/5”
- 54 kpix
- 6 HEMTs

Main array
- 1” pixels, 5’ FOV, 50 um pixels
- ~ 3 eV, 10 cps/hydra (5”)
- up to 7 keV
- 86.4 kpix
- 10 HEMTs

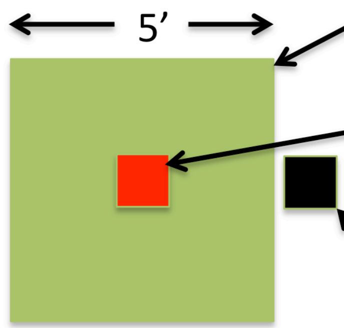
Enhancement main array:
- 0.5” pixels, 1’ FOV, 25 um pixels
- ~ 1.5 eV, 10-20 cps/hydra-25 (2.5”)
- up to 7 keV
- 12.8 kpix
- 6 HEMTs

No Hi-res inner array

Ultra-hi-res array
- 1” pixels, 1’ FOV, 50 um pixels
- 0.3-0.4 eV (up to ~ 0.75 keV)
- Count rate ~ 80 cps/1”
- 3.6 kpix
- 6 HEMTs

Lynx X-ray Microcalorimeter Array Layout

No Extended array!



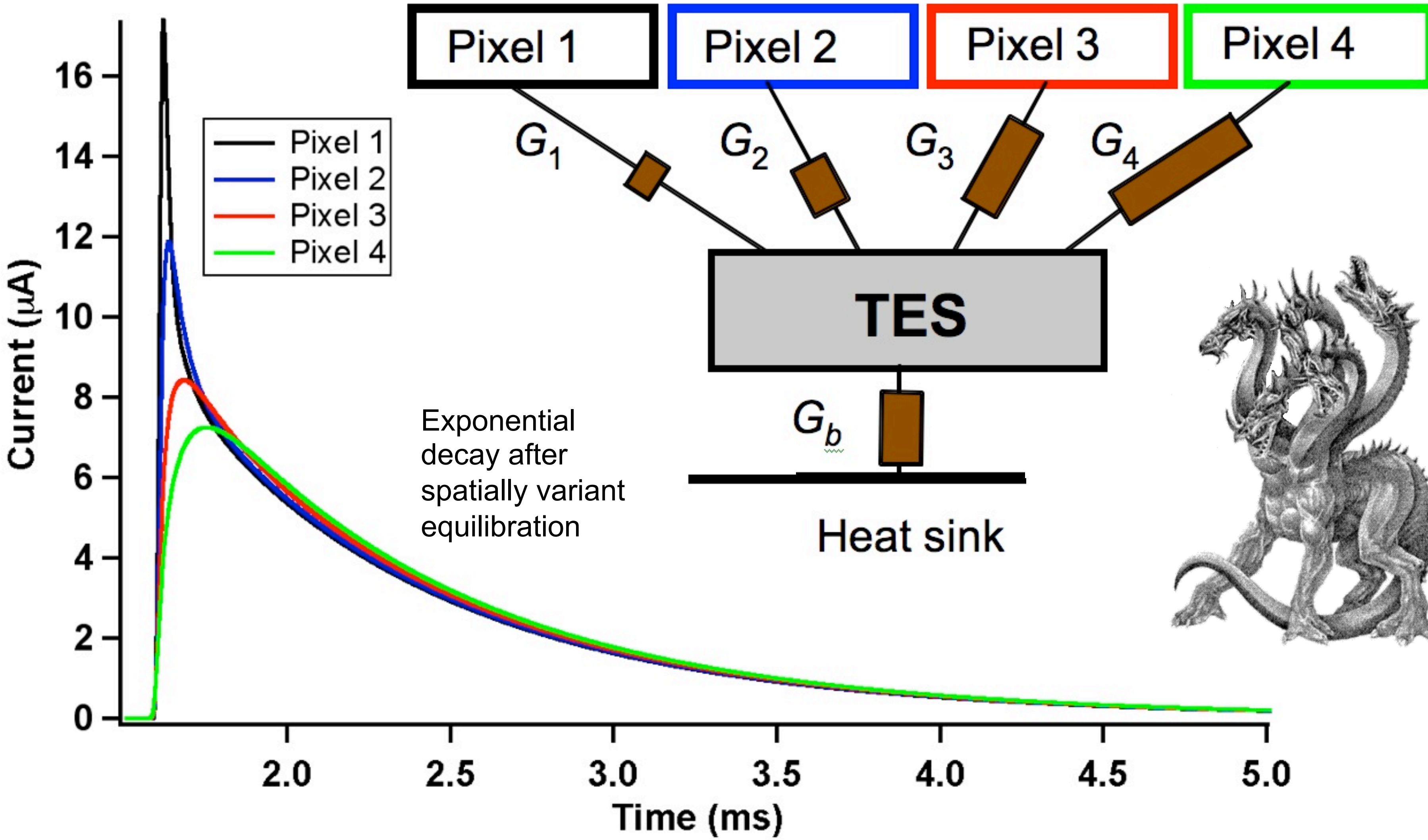
Main array
- 1” pixels, 5’ FOV, 50 um pixels
- ~ 3 eV, 10 cps/hydra (5”)
- up to 7 keV
- 86.4 kpix
- 10 HEMTs

Enhancement main array:
- 0.5” pixels, 1’ FOV, 25 um pixels
- 1.5 eV, 10-20 cps/hydra-25 (2.5”)
- up to 7 keV
- 12.8 kpix
- 6 HEMTs

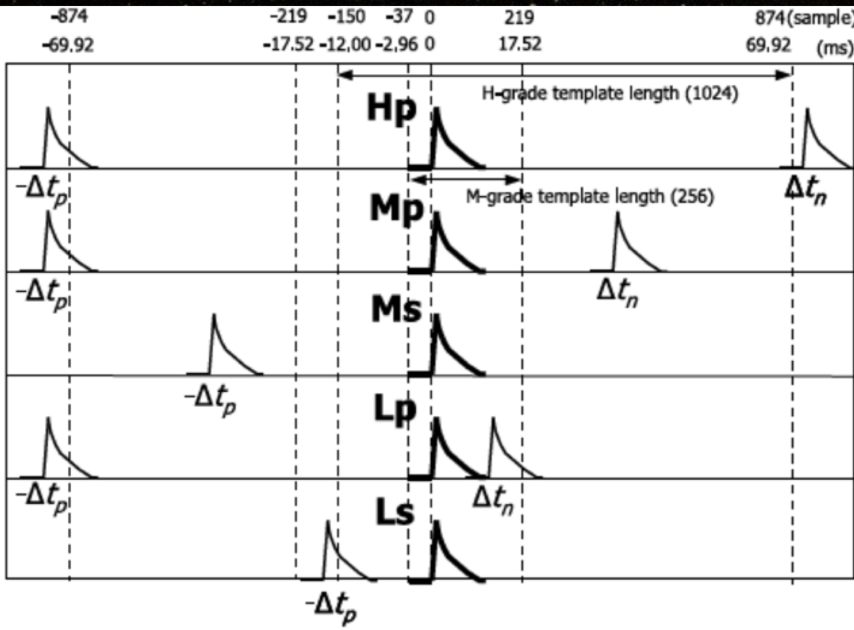
No Hi-res inner array

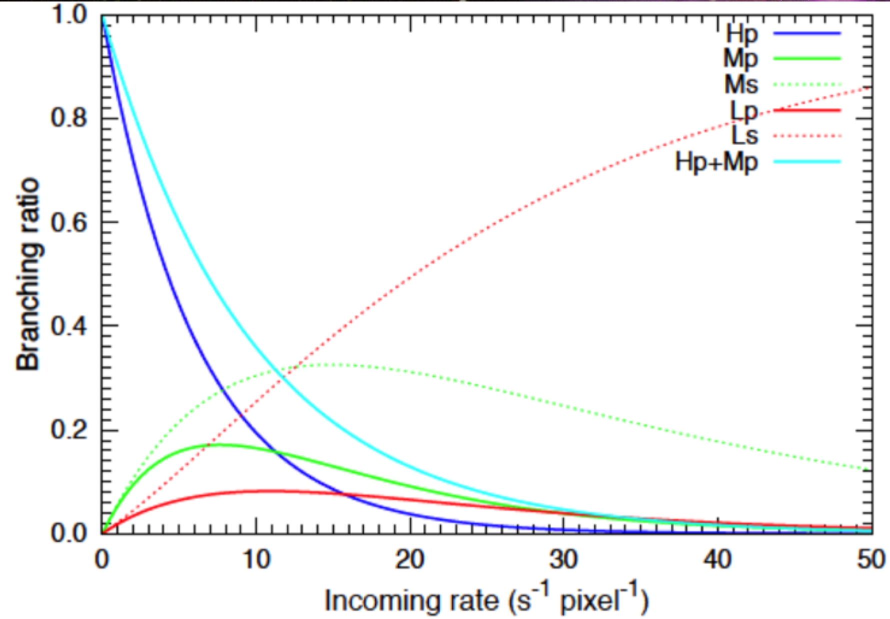
Ultra-hi-res array
- 1” pixels, 1’ FOV, 50 um pixels
- 0.3-0.4 eV (up to ~ 0.75 keV)
- Count rate ~ 80 cps/1”
- 3.6 kpix
- 6 HEMTs

Do we need the Hi-res inner array?
Hydras and count rates



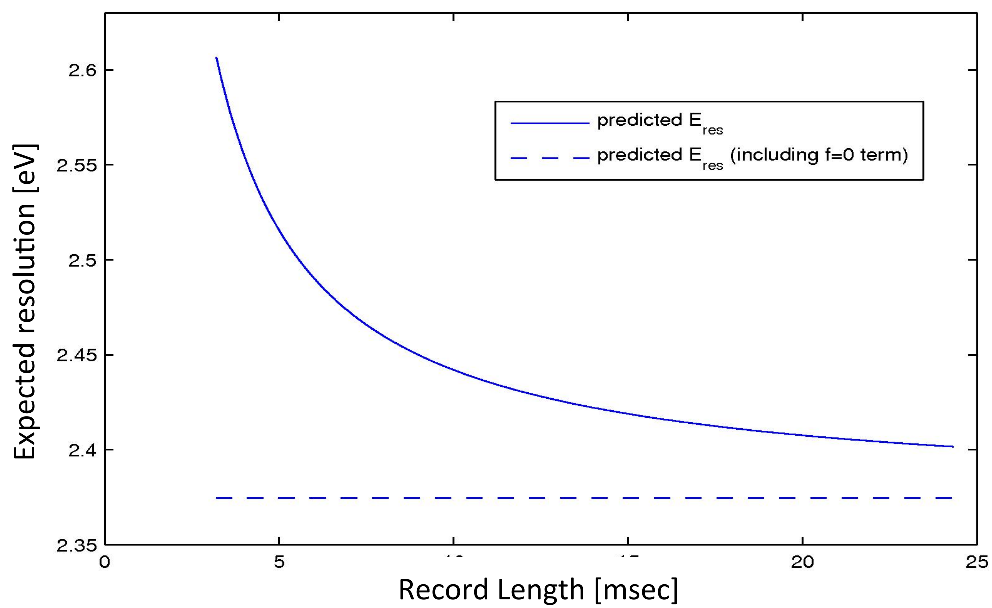
Event grades





Function of time since previous pulse (Δt_p) & to next pulse (Δt_n)

- f=0 term in optimal filter must be discarded, contains less info as record grows longer:



Do we need the Hi-res inner array?

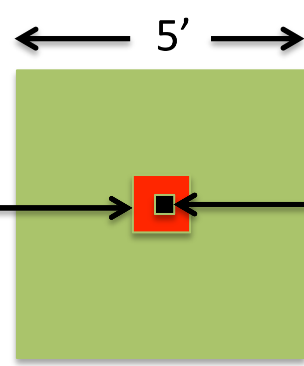
Enhanced main array:

Energy Resolution	• 2 eV (FWHM) (hi-res) • 4 eV (FWHM) (mid-res) • 10 eV (FWHM) (low-res)
Count-rate capability	• **10-20 cps/hydra (0.1-0.2 mC) *hi-res*** (per 25 contiguous pixels) • **40-80 cps/hydra (0.8-0.8 mC) *mid-res*** • **150-300 cps/hyd. (1.5-3 mC) *low-res***

Hi-res inner array:

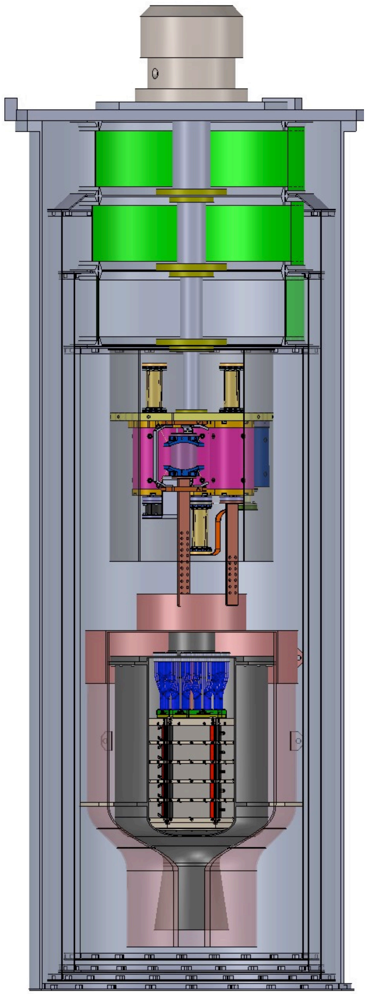
Energy Resolution	• 2 eV (FWHM) (hi-res) • 4 eV (FWHM) (mid-res) • 10 eV (FWHM) (low-res)
Count-rate capability	• **20 cps/hydra (0.2 mC) *hi-res*** (per 4 contiguous pixels 1"x1") • **80 cps/hydra (0.8 mC) *mid-res*** • **300 cps/hydra (3 mC) *low-res***

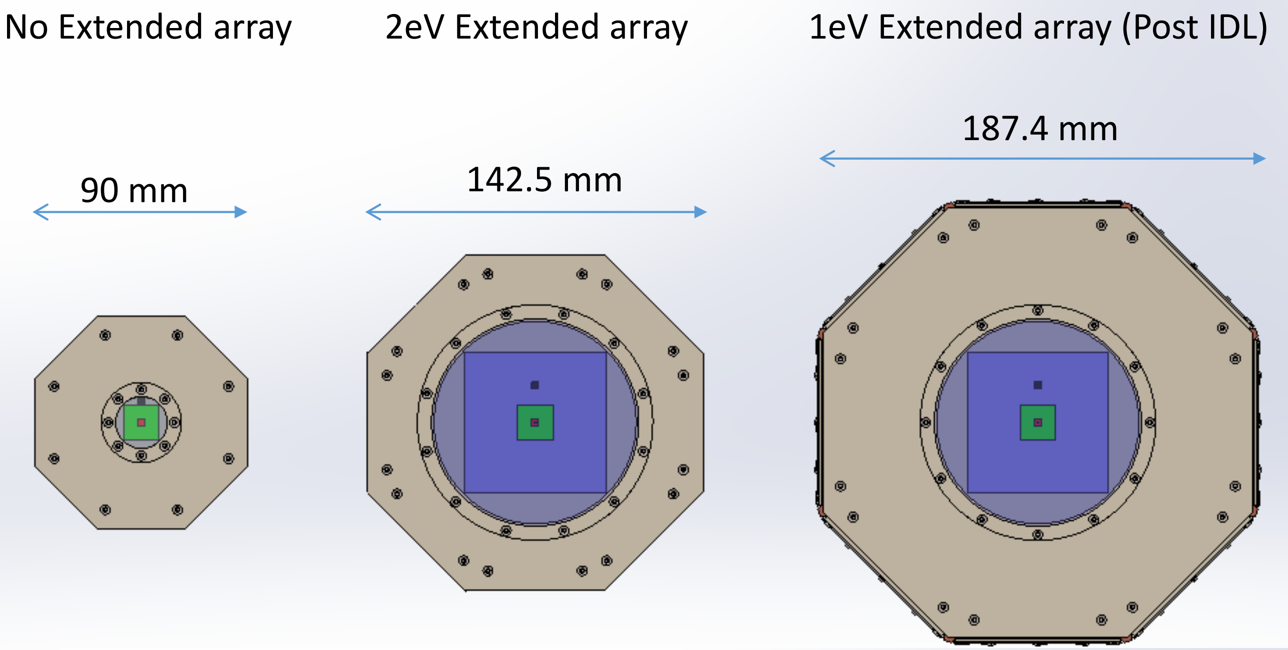
Enhanced main array:
- 0.5” pixels, 1’ FOV, 25 um pixels
- ~ 1.5 eV, up to 7 keV
- 10-20 cps/hydra-25 (2.5”)
- 12.8 kpix, 6 HEMTs
- **Avg. 0.4-0.8 cps/pixel**

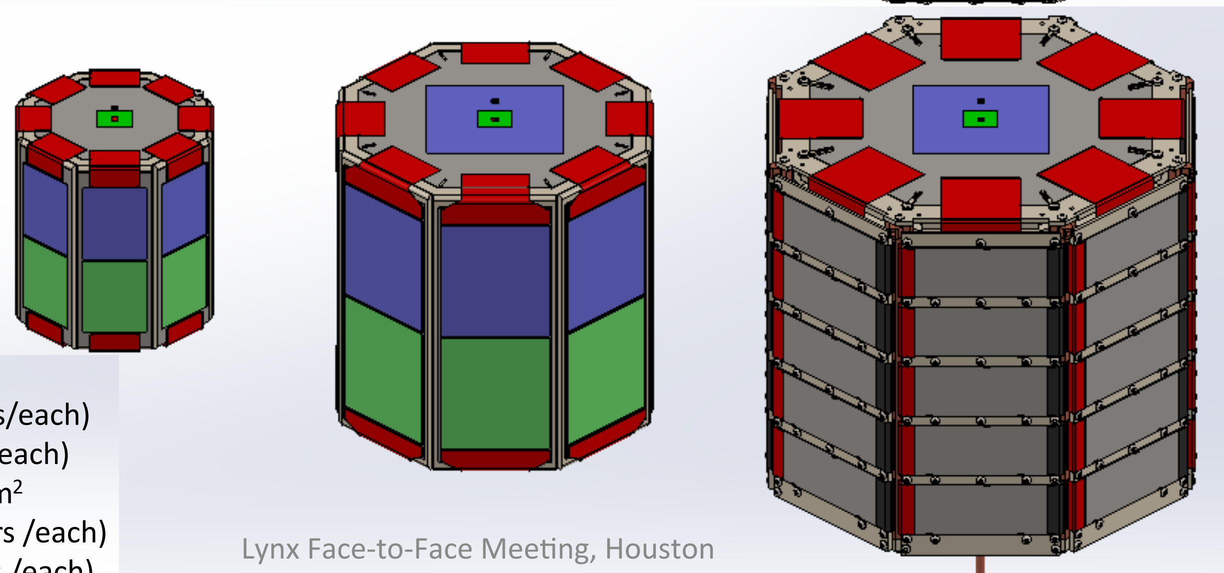


Hi-res inner array:
- 0.5” pixels, 20” FOV, 25 um pixels
- ~ 1.5 eV, up to 7 keV
- 20 cps/hydra-4 (1”),
- 1.6 kpix, 4 HEMTs
- **Avg. 5 cps/pixel**

3 Different Mechanical Designs



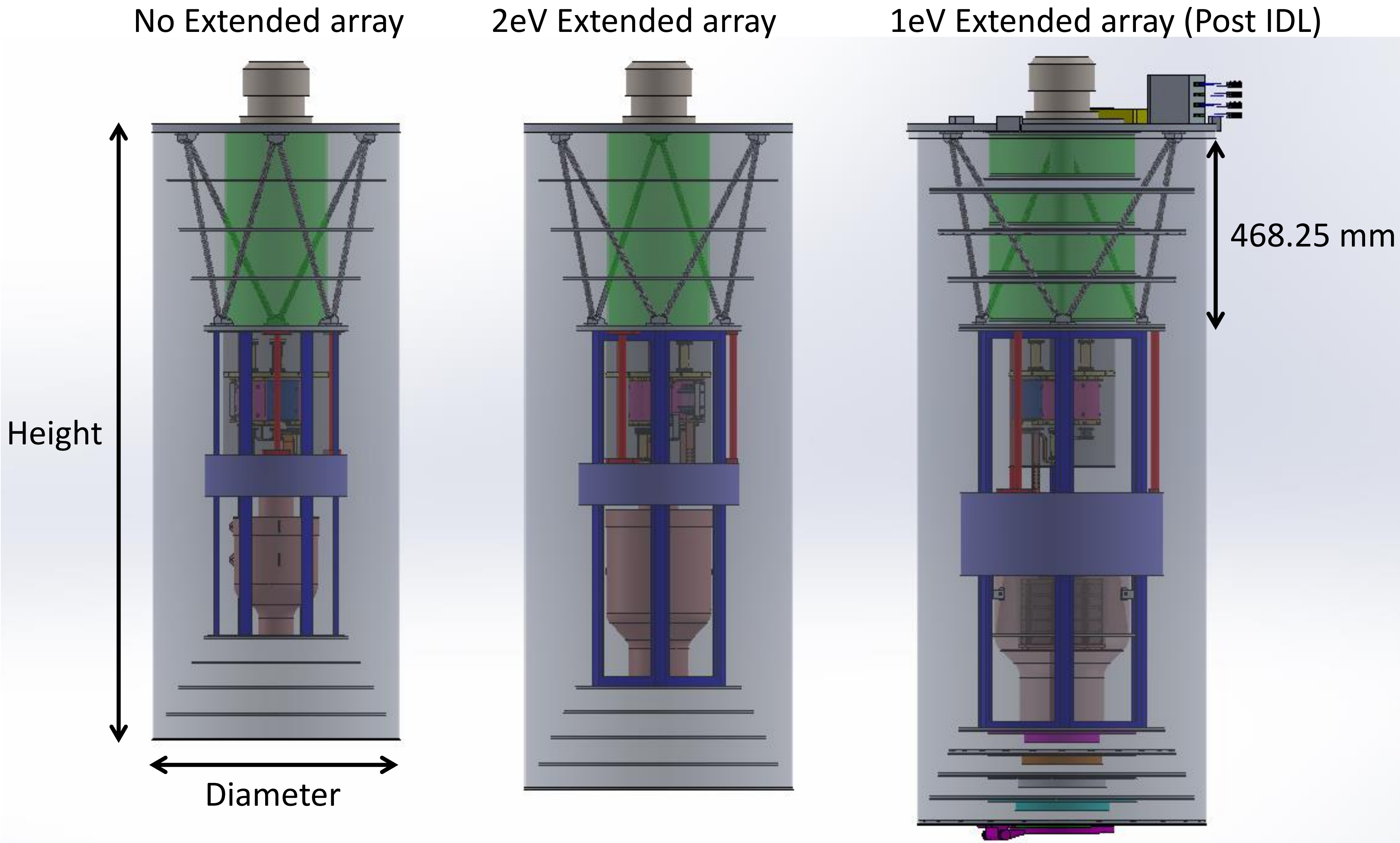




Blue: Nyquist inductor, 1 inductor = 1 mm^2
- 2eV Extended : 48 mm x 56 mm (2688 inductors/each)
- No Extended: 28 mm x 36 mm (1008 inductors/each)

Green: Microwave resonators, 1 resonator = 1 mm^2
- 2eV Extended: 48 mm x 56 mm (2688 resonators /each)
- No Extended: 28 mm x 36 mm (1008 resonators /each)

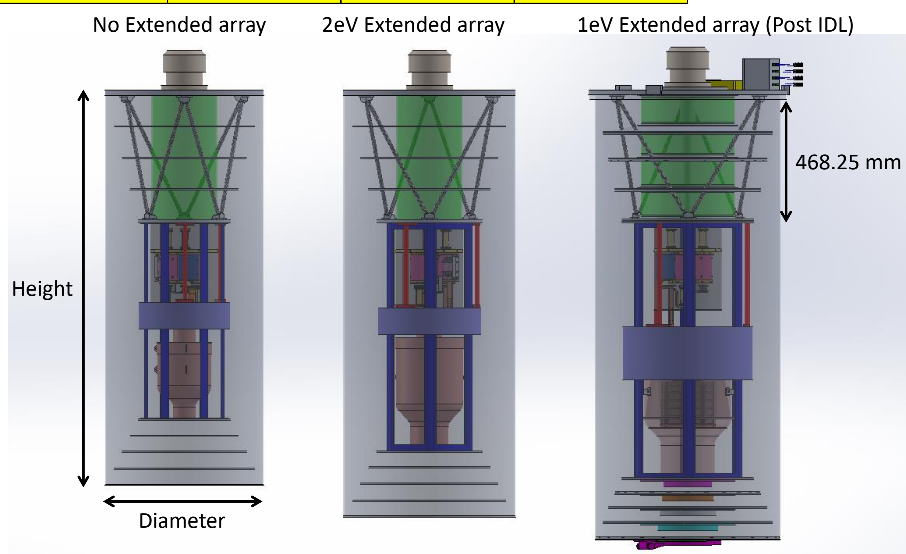
3 Different Mechanical Designs!



Mass

LXM	Mass kg	O.D. cm	Length cm
IDL	735	121	164
Updated after IDL	606	70	166
Updated with 2 eV extended array	559	65	155
Updated with no extended array	515	60	143

- These estimates have updated mechanical models



Cost

LXM	**Basic Instrument** $M	**Total w/wraps** $M	**Total with further 20% margin $M**
IDL	354	467	**561**
Updated after IDL – 1 eV *Extended Array*	300	396	**475**
Updated with 2 eV *Extended Array*	281	371	**445**
Updated with no *Extended Array*	255	337	**404**

- Different options not yet re-costed – this is a WAG
- This WAG presented at STDT telecon in October
- Provides a rough idea of cost differences
- In-house center management & overhead charge may need to be added as well

Extended Array Decision?

LXM	**Basic Instrument** $M	**Total w/ wraps** $M	**Total with further 20% margin $M**	**Mass** **kg**
Updated after IDL - 16 HEMTs in inner 5'	300	396	**475**	**606**
Updated with 2 eV extended array	281	371	**445**	**559**
Updated with no extended array	255	337	**404**	**515**

- Maximum power addressed next, but does not depend on this choice since plan is to operate *Extended Array* or inner 5' region, but not simultaneously
- Ultimately margins may allow to upgrade inner + outer simultaneous operation, but not baselined now.

Is the additional science capability worth the extra mass/cost/complexity?

Power - IDL

Electrical Components	Qty.	Power, ea (Watts)	Total Power (Watts)	Mass, each (Kg)	Total Mass (Kg)
MEBs	1A/1B	20.1	20.1	3.7	7.4
DEEP Boxes	2	960	1,920	33.8	67.6
RF Electronics Boxes, including power conversion	2	85	170	30	60
Junction Box	1	5	5	1.7	1.7
MXS Control Electronics, including HVPS (2), controls 4 primary and 4 backup sources	1A/1B	20	20	2	4
ADRC Electronics (internally redundant)	1	60	60	*	*
CryoCooler + Electronics (set of MCU & TAU)	1A/1B	750	750	*	*
Op. Heaters (thermostat)**	1A/1B	50	50	*	*
Total Mass & Power:			**2,995**		**140.7**

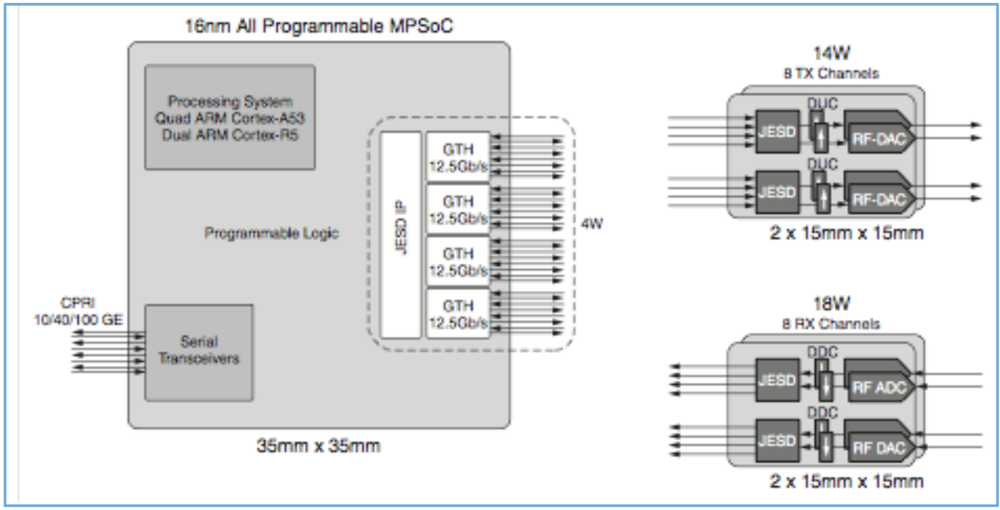
Power reduction – independent of *Extended Array* decision

Power	**Watts**
Total - IDL - 20 HEMTs	**2,995**
DEEP Power - IDL - 20 HEMTs, 30 W/FPGA	1,920
DEEP Power - 16 HEMTs, 20 W/FPGA	1,136
DEEP Power - RF-Soc	~116 to 414
Cryocooler power - IDL	750
Cryocooler baseline (PT cooler - TBR)	507
Cryocooler alternative (T.B. cooler TBR)	340
New baseline: 16 HEMTs, 20 W/FPGA, PT cooler	**1,832**
Low TRL option: 16 HEMTs, RFSoc, TB cooler	~645 to 943
Savings (baseline):	1,163

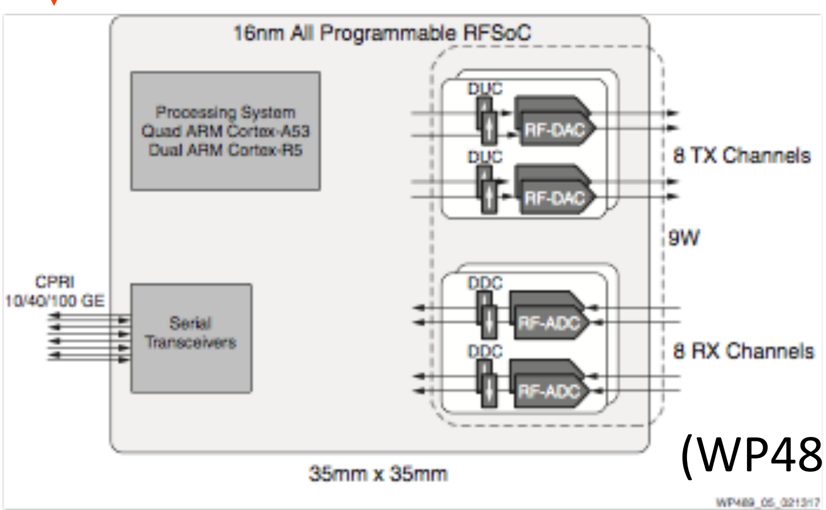
- **Thermal modeling currently being revised after updated mechanical design**
- Next: Power loads for pulse tube cooler & turbo-brayton cooler to be updated as part of CAN studies.

Xilinx RFSoC (Radio-Frequency Signal on a Chip)

- Embedded high-speed ADCs/DACs
  - Reduces external interfaces (signal and clock)
  - Allows low voltage signals
  - Significant power and size saving
- 12-bit 4Gsps ADC (x8)
- 14-bit 6.4Gsps DAC (x8)
- May be able to interface ≧2 HEMTs
  - 2 ADCs / 2 DACs required per HEMT
- Starting to become available commercially now
  https://www.xilinx.com/products/silicon-devices/soc/rfsoc.html
- Radiation tolerant versions could be ~ 10 years away.



(ADC/DAC+I/O): 36W → 9W



(WP489)

Xilinx RFSoC

- Assuming 4 Gsps ADC (x8) and DAC (x8) per FPGA
- One RFSoC FPGA can read out up to 4 HEMTs
- 2 ADCs & 2 DACs with 4 Gsps required per HEMT
- 20 W per FPGA – result of calculation based upon resources needed (see backup)

Scenario	# of HEMTs required	RFSoC Unit Power			# of FPGA's required	LXM DEEP Total (W)
		FPGA (W)	ADC/DAC +I/O (W)	Total (W/RFSoC)		
1 RFSoC / 1 HEMT	16	20	9	29	16	464
1 RFSoC / 2 HEMT	16	20	9	29	8	232
1 RFSoC / 4 HEMT	16	20	9	29	4	116

* ADC/DAC+I/O power numbers taken from Xilinx white paper (WP489)

What happens next for LXM design & costing?

- After STDT array layout decision:

1. ROSES supported prototype Lynx detector array designs (TES & Magcal) will be updated − new designs in April.
2. Master equipment list (MEL) generated for one of the mechanical models.
3. Heat loads at different temperatures with new designs being calculated currently. These will determine final power estimates for cryocooler.
4. Cryocooler designs will be refined within CANS, including mechanical detailed model designs.
5. Cost estimates currently being generated for different cryocooler options.
6. LXM schedule updated according latest mission timeline. Software assumptions being revisited.
7. In about a month, whole LXM will be re-costed. - CM&O will be looked at more closely.
8. As part of one CAN study, design of cryostat will be further developed to show structure needed to survive launch.

Missing Requirements for LXM

Requirements needed/ Potential science drivers	**Current spec**
1. Energy Resolution of *Extended Array* if we keep it? 2. If a 2 eV *Extended Array*, does pixel size need to be 5" is 10” ok?	1 or 2 eV
3. Are assumed count rate capabilities of LXM pixel types sufficient? Need to consider: (a) count rate per hydra and not just per pixel (b) different event grades (hi-res, mid-res, and low-res events) -depends on arrival time X-ray event compared to previous and next X-ray.	Various
4. Field of view of *Ultra High-res array* What is the max angular size of objects for which 0.4 eV spectral resolution is required?	1x1 arcmin
5. Throughput at 6 keV in *Main*, *Enhanced* & *High-Res Inner Arrays* What Fe-K line science drives LXM design?	TBD

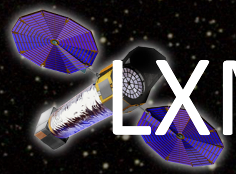
Missing Requirements for LXM

Requirements needed/ Potential science drivers	Current spec
6. For IR blocking filters, what has higher priority, area at 6 keV or area well below 0.6 keV? (Most filter options a wash around 0.6 keV)	TBD
7. How quickly do wings of optic psf fall off? Is it sufficient to study hot gas flows and jets close to AGN with sufficient contrast? 8. Feedback group suggested that, "for local (bright) AGN, characterization requires sensitivity up to 8-10 keV with an energy resolution of 3 eV to resolve the ~100km/s substructure that may exist in these winds. These local AGN will also set requirements for micro-calorimeters bright source capabilities (being in the few millicrab range)." - 3 eV wont be possible simultaneously with measurements extending up to 10 keV, is this ok? - Is the count rate capability in the inner 5' region sufficient?	
9. What are the instrument background requirements (all pixel types)? Athena X-IFU requirement: < 5×10^{-3} cts cm^{-2} $s^{-1}keV^{-1}$. Adequate for Lynx LXM?	< 5×10^{-3} cts cm^{-2} $s^{-1}keV^{-1}$

Backup

LXM Specs (Main Array)

LXM Main Array Parameter	Requirement (Red-Team Interim Report)	Requirement Status	Science Driver	Notes
Main Array (Excluding Central arcminute)				
Energy Range (keV) Minimum Maximum	0.2 7 keV for 3 eV normal mode ~15 keV for 5 eV hi-E mode	OK OK OK	Need to extend energy range to determine continuum for studying various AGN. At low end to see low temp. thermal emission or low energy non-thermal sources.	Low-res mode achieved by increasing the bath temperature
Quantum Efficiency (keV)	Area fill factor > 90% Vertical Q.E. > 95% at 7 keV?	Best achieve. Derived/N.C.	Maximization of effective area (counts) / minimization of observation times.	Limited by: - area fill-factor, - IR blocking filter design - absorber thickness (7 keV requirement would be good.)
Field of view	5x5 arc-min	OK	Characteristic size of many extended objects (SNR, galaxies and clusters of galaxies) for high-res imagining and spectroscopy	A few larger images can be acquired through mosaicking observations
Pixel size (arcsec)	1 x 1	OK	Removal of point sources to minimize background in diffuse emission, to study arc-second scale features such as shocks and filaments, & point sources in crowded regions (XRBs and stars)	Smaller pixels off axis not essential and would require too many sensors to read out
Energy Resolution	• 3 eV (FWHM) (hi-res mode) • 5 eV (FWHM) (mid-res mode) • 10 eV (FWHM) (low-res mode)	OK	Line-separation /velocity accuracy to determine energetics and dynamics of plasmas.	Sufficient for required plasma diagnostics and energetics.
Count-rate capability	• 10 cps/hydra (0.1 mC) in hi-res mode (per 25 contiguous pixels) • 40 cps/hydra (0.4 mC) in mid-res mode • 150 cps/hydra (1.5 mC) in low-res mode	NC	Accommodation of typical flux of interesting sources.	Essentially the count-rate per point source.
Timing resolution/accuracy	• Resolution: 2 µs • Accuracy = 50 µs	OK		Resolution determined by read-out sample rate. Accuracy determined distributed clock accuracy.



LXM Specs (Enhanced Main Array)

Central arcminute, excluding High-res inner array

SRB v3

LXM Enhanced Main Array Parameter	Requirement (Red-Team Interim Report)	Requirement Traceability Status	Science Driver	Notes
Energy Range (keV) Minimum Maximum	0.2 7 keV for 3 eV normal mode ~15 keV for 5 eV hi-E mode	OK OK OK	Need to extend energy range to determine continuum for studying various AGN. At low end to see low temp. thermal emission or low energy non-thermal sources.	Low-res mode achieved by increasing the bath temperature
Quantum Efficiency (keV)	Area fill factor > 90% Vertical Q.E. > 95% at 7 keV?	Best achieve. To be discussed	Maximization of counts / minimization of observation times	Limited by: - area fill-factor, - IR blocking filter design - absorber thickness (6 keV requirement would be good.)
Field of view	1x1 arcmin	OK	Minimum size of fine structure in objects requiring extremely high angular resolution, such as jets, centers of galaxies, and cores of clusters of galaxies.	
Pixel size (arcsec)	0.5 x 0.5	OK	Study of sub-arc-second scale features such as shocks and filaments, & point sources in crowded regions (XRBs and stars). Study of distribution of AGN within and around groups/clusters, removing AGN, study of thermodynamic properties of cluster gas. Feedback in in groups and clusters.	
Energy Resolution	• 2 eV (FWHM) (hi-res) • 4 eV (FWHM) (mid-res) • 10 eV (FWHM) (low-res)	OK OK	Line-separation /velocity accuracy to determine energetics and dynamics of plasmas. For z=1, when SMBH growth and AG feedback at peak, features red-shifted to 3-4 keV, requiring 1.5-2 eV resolution.	1.5 eV possible
Count-rate capability	• 10-20 cps/hydra (0.1-0.2 mC) in hi-res mode (per 25 contiguous pixels) • 60-80 cps/hydra (0.1-0.2 mC) in mid-res mode • 150-300 cps/hydra (0.1-0.2 mC) in low-res mode 20 cps/hydra (per 25 contiguous pixels)	To be discussed	Accommodation of typical flux of interesting sources.	Essentially the count-rate per point source.

LXM Specs (High-res Inner Array)

SRB v3

LXM High-res Inner Array Parameter	Requirement (Red-Team Interim Report)	Requirement Traceability Status	Science Driver	Notes
Energy Range (keV) Minimum Maximum	0.2 7 keV for 3 eV normal mode ~15 keV for 5 eV hi-E mode	OK OK OK	Need to extend energy range to determine continuum for studying various AGN. At low end to see low temp. thermal emission or low energy non-thermal sources.	Low-res mode achieved by increasing the bath temperature
Quantum Efficiency (keV)	Area fill factor > 90% Vertical Q.E. > 95% at 7 keV?	Best achieve. To be discussed	Maximization of counts / minimization of observation times	Limited by: - area fill-factor, - IR blocking filter design - absorber thickness (6 keV requirement would be good.)
Field of view	20x20 arcsec	OK	Need to center AGN on this region	Size needed to center AGN in this region of the array based upon pointing accuracy.
Pixel size (arcsec)	0.5 x 0.5	OK	Study of sub-arc-second scale features such as shocks and filaments, & point sources in crowded regions (XRBs and stars)	
Energy Resolution	• 2 eV (FWHM) (hi-res mode) • 4 eV (FWHM) (mid-res mode) • 10 eV (FWHM) (low-res mode)	OK OK	Line-separation /velocity accuracy to determine energetics and dynamics of plasmas.	1.5 eV possible
Count-rate capability	• 20 cps/hydra (0.2 mC) in hi-res mode (per 4 contiguous pixels 1"x1") • 80 cps/hydra (0.8 mC) in mid-res mode • 300 cps/hydra (3 mC) in low-res mode	To be discussed	To do hi-res spectroscopy of point sources, studies of velocities of AGN winds, and flares from jets.	Feedback group suggested a few mC capability is necessary

LXM Specs (Ultra-high-res Array)

SRB v3

LXM Ultra-hi-res Array Parameter	Requirement (Red-Team Interim Report)	Requirement Traceability Status	Science Driver	Notes
Energy Range (keV) Minimum Maximum	 0.2 0.75	OK	To study faint diffuse baryons in emission, such as galactic halos	The highest energy resolution available for studies of velocities from lines up to O VIII. R~ 2000.
Quantum Efficiency (keV)	Area fill factor > 90% Vertical Q.E. > 99% at 0.75 keV IR blocking filter throughput is largest factor affecting detection efficiency.	OK	Maximization of counts / minimization of observation times	There are some trade-offs in filter designs - affecting whether 6 keV area is more important or area for energie below 0.6 keV.
Field of view	1x1 arcmin	To be discussed	To sample enough of the hot gas around galaxy halo gas	Need enough photons to measure velocities of outflows.
Pixel size (arcsec)	1 x 1	OK	To reduce the back-ground	To get the required energy resolution!
Energy Resolution	• 0.4 eV (FWHM) (hi-res mode) • 0.8 eV (FWHM) (mid-res mode) • 2 eV (FWHM) (low-res mode)	OK	Need R~ 2000 to measure velocities/turbulent broadening down to ~50 km/s (outflows and thermal velocities).	As good energy resolution as 0.3 eV may be possible.
Count-rate capability	• 80 cps/1” pixels (0.8 mC) • 320 cps/pixel (3.2 mC) in mid-res mode • 1000 cps/pixel (10 mC) in low-res mode	To be discussed	No driver. Pixel design naturally does this.	Will naturally be very high - will try to develop to make lower to make it easier to read out. Count rates capability may be reduced by X-rays beyond 0.75 keV

LXM Specs (Extended Array)

SRB v3

LXM Extended Array Parameter	Requirement (Red-Team Interim Report)	Requirement Traceability Status	Science Driver	Notes
Energy Range (keV) Minimum Maximum	 0.2 2.0	OK	Galactic halos and outskirts of clusters and groups galaxies. Line intensity mapping	Pixels will not be deigned to have high QE above 2 keV.
Quantum Efficiency (keV)	Area fill factor > 98% Vertical Q.E. > 60% at 2 keV >98% at 1 keV IR blocking filter throughput is largest factor affecting detection efficiency.	Derived	Maximization of counts / minimization of observation times	There are some trade-offs in filter designs - affecting whether 6 keV area is more important or area for energie below 0.6 keV.
Field of view	20x20 arcmin	To be discussed	Need large grasp to efficiency map out large extended regions.	
Pixel size (arcsec)	5 x 5	To be discussed	The removal of point sources contaminating measurements.	Is it known that 5" pixels are really needed rather than 10"?
Energy Resolution	• 1 or 2 eV (FWHM) (hi-res mode) • 2 or 4 eV (FWHM) (mid-res mode) • 4 or 8 eV (FWHM) (low-res mode)	To be discussed	Plasma diagnostics. Separation of source/background emission.	This is the biggest question that needs to be answered!!! It's a cost trade-off.
Count-rate capability	• 20 cps/5" pixel (0.2 mC) or 20 cps/hydra (2 eV) • 80 cps/pixel (0.8 mC) in mid-res mode • 300 cps/pixel (3 mC) in low-res mode	To be discussed	No driver -	No driver - need to make slow to make this possible to read out.

Virtex-5 power estimator